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Numerical Investigation of Large Particles in Upward Pipe Flow with Sinusoidal Wall Boundary Condition

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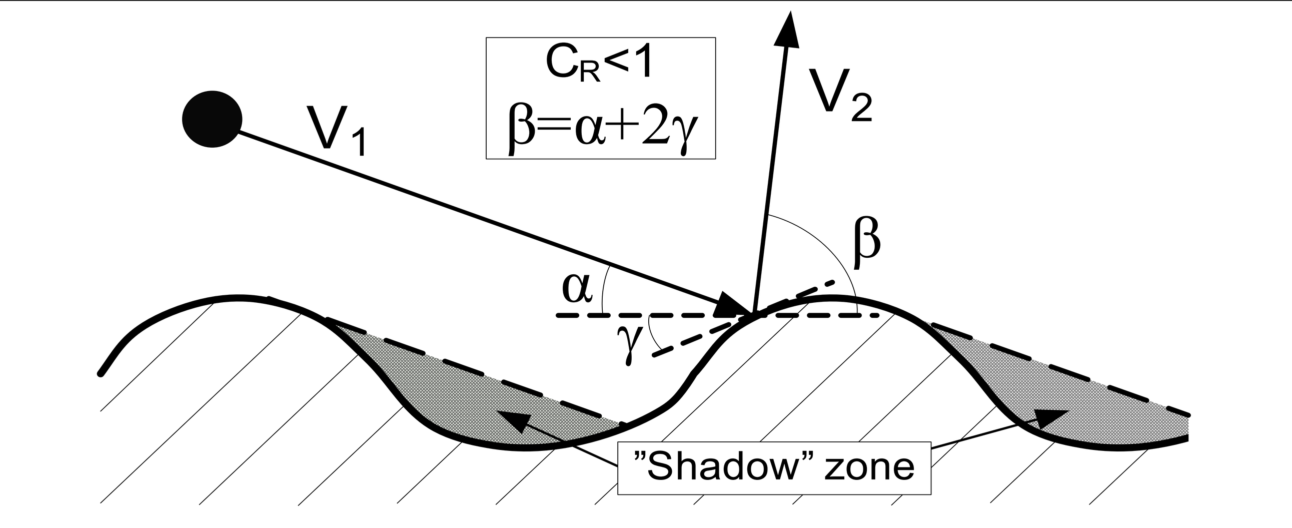
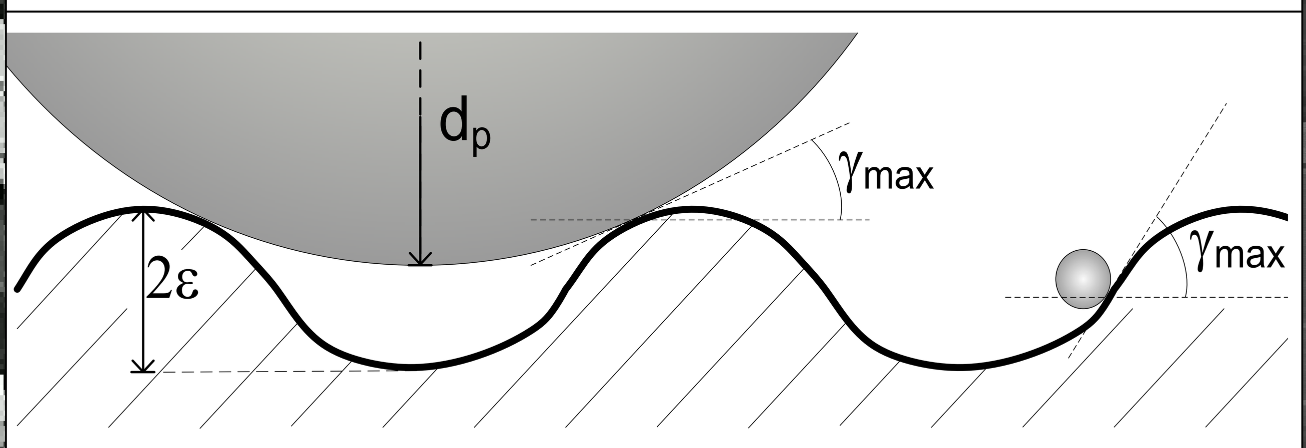
Abstract

Numerical simulation of upward turbulent particle-laden pipe flow is performed with the intension to reveal the influence of surface roughness on the velocity statistics of the particle phase. A rough wall collision model, which models the surface as being sinusoidal, is proposed to account for the wall boundary condition ranging for smooth surfaces to very rough surfaces. Simulations are performed using the Eulerian-Lagrangian methodology for the dilute one-way coupling regime. Results are reported for 3 sizes of glass spheres: 50μm, 200μm and 550μm.

Model

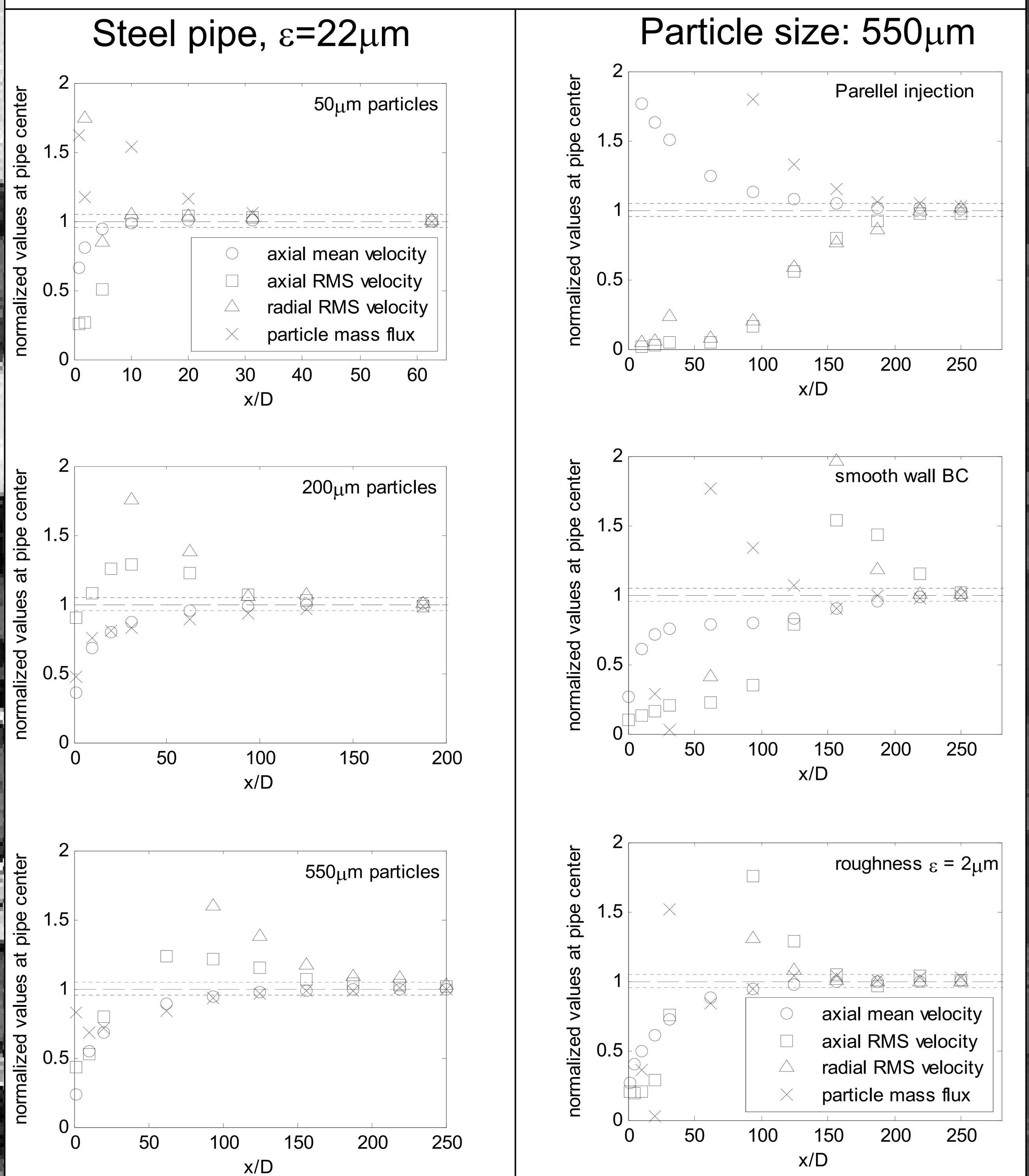
A rough wall boundary condition has been implemented into a CFD context by assuming a sinusoidal surface. The shadow effect and the geometric constraints are included by limiting the range of the inclination angle. For each collision the range of possible collision within the 2π period of the sinus function is calculated according to the "shadow" zone which occurs for small impact angles α. Thereafter the inclined plane which the particle collides with is determined using a uniform random function.





Effect on Entry Length

For all cases the particles RMS velocity takes a considerable longer distance to become fully developed compared to the mean velocity. There is a clear correlation between the entry length and the particle size and the largest particles require up to 200 pipe diameters before fully developed conditions are achieved. There does not seem to be a strong correlation between development length and the surface roughness. For the ideal collision with a perfectly smooth wall the entry length increases significant whereas simulation considering an almost smooth wall produce better results.

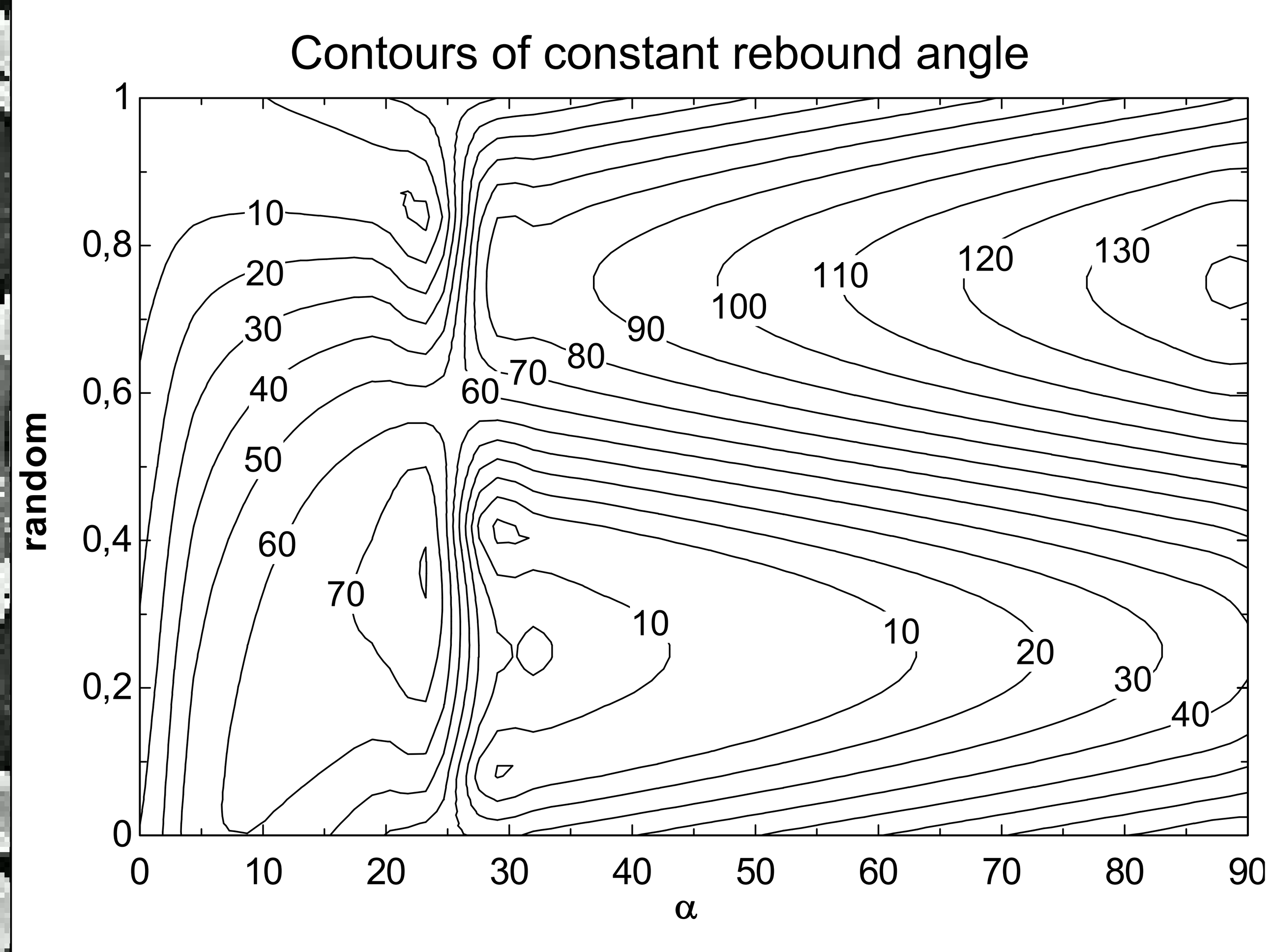


Conclusions

Particle statistics are greatly affected by the wall BC. As such, the mean axial velocity at the centerline was up to *7% higher* for smooth wall BC compared to rough wall BC while the particle TKE was similarly found to be *two orders of magnitude greater*. The particle RMS velocities require somewhat longer time/distance compared to the mean velocity before the flow can be considered to be fully developed. The entry length was not found to depend on the surface roughness.

Performance Map

Due to the shadow effect small impact angles result in a greatly enhanced normal coefficient and the particles tend to 'jump' out normally to the wall. For larger impact angles the shadow effect abates and the rebound angles becomes fully random.a large ratio between the particle diameter and the surface roughness will only yield small maximum inclination angles whereas the opposite, a small particle diameter relative to the surface roughness, will result in larger maximum inclination angles.



Influence of Roughness, d_p=550μm

It is necessary to take the surface roughness into account to correctly predict the particle RMS velocity. The surface roughness tends to reduce the mean velocity of the particles and increase the concentration at the centerline of the pipe. The present results are overall found to agree with that of Mathiesen et al. (2008) and this shows the importance of using correct wall boundary conditions to predict the particle RMS velocity. The particle RMS velocity is stongly coupled to the surface roughness of the wall and results show that the particle velocity reaches a maximum level where an additional increase in surface roughness yields no increase in the RMS and mean slip velocity.